Ionosphere laboratory exercise

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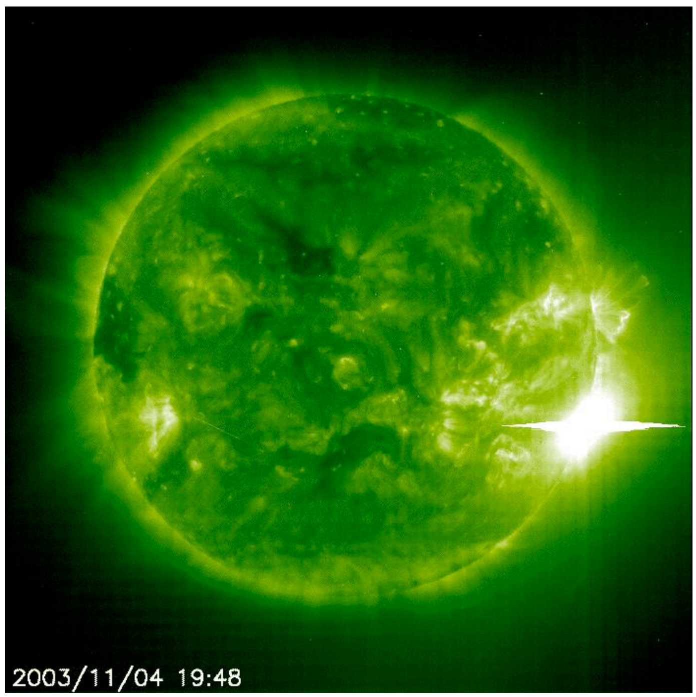
This exercise aims to help you understand better the interaction between solar storms and the Earth's ionosphere. Questions for you are in red.

1.1. Scope of the exercise

On October 28, 2003, a series of solar flares and coronal mass ejections began, which spread their effect throughout the heliosphere for over a month. Known as The Halloween storms, these were some of the strongest ejections of mass and light from the Sun in the last 20 years. In this exercise, we will follow the changes to the Earth's ionosphere caused by the first storm on 28 October.

The image below was made by the Solar and Heliospheric Observatory (SOHO) satellite, and it shows the solar flare on November 11, 2003 – the strongest flare ever observed in X-ray light.



1.2. Virtual ionospheric observatories

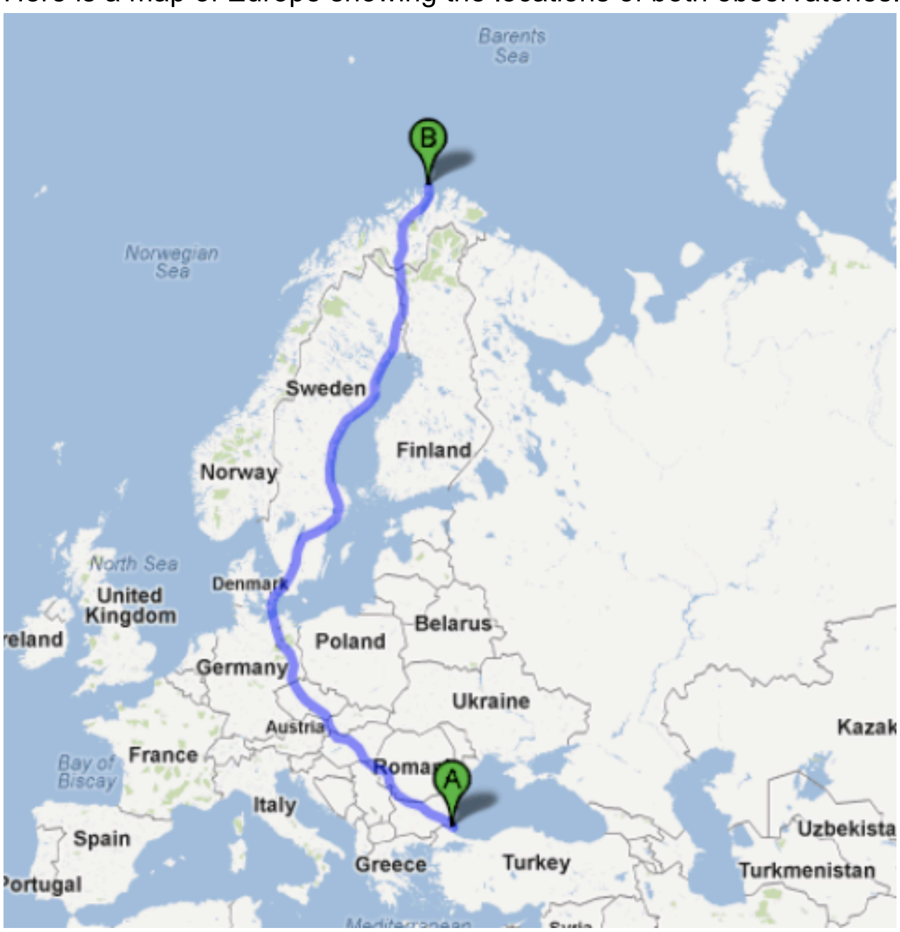
To see how the ionosphere changes during a solar storm, we will look at results from an empirical model, called ABBYNormal (http://ccmc.gsfc.nasa.gov/models/modelinfo.php?model=ABBYNormal), which models the dynamics of the ionosphere. This model can be easily configured to produce results for different dates and locations on the surface of the Earth. In order to see the effect of the Halloween storms on the ionosphere, we will situate two virtual observatories from which we will 'observe' the ionosphere using the ABBYNormal model. The first location is a camping ground on the

Black Sea – Silistar, Bulgaria (Lat 42.02N, Lon 28.0E). The second one is the northernmost point in mainland Europe – Nordkapphallen, Norway (Lat 71.17N, Lon 25.78E). These two spots are quite separated in latitude, which will allow us to see how the ionosphere behaves differently at middle and high latitudes.

Silistar, Bulgaria (Lat 42.02, Lon 28.0)

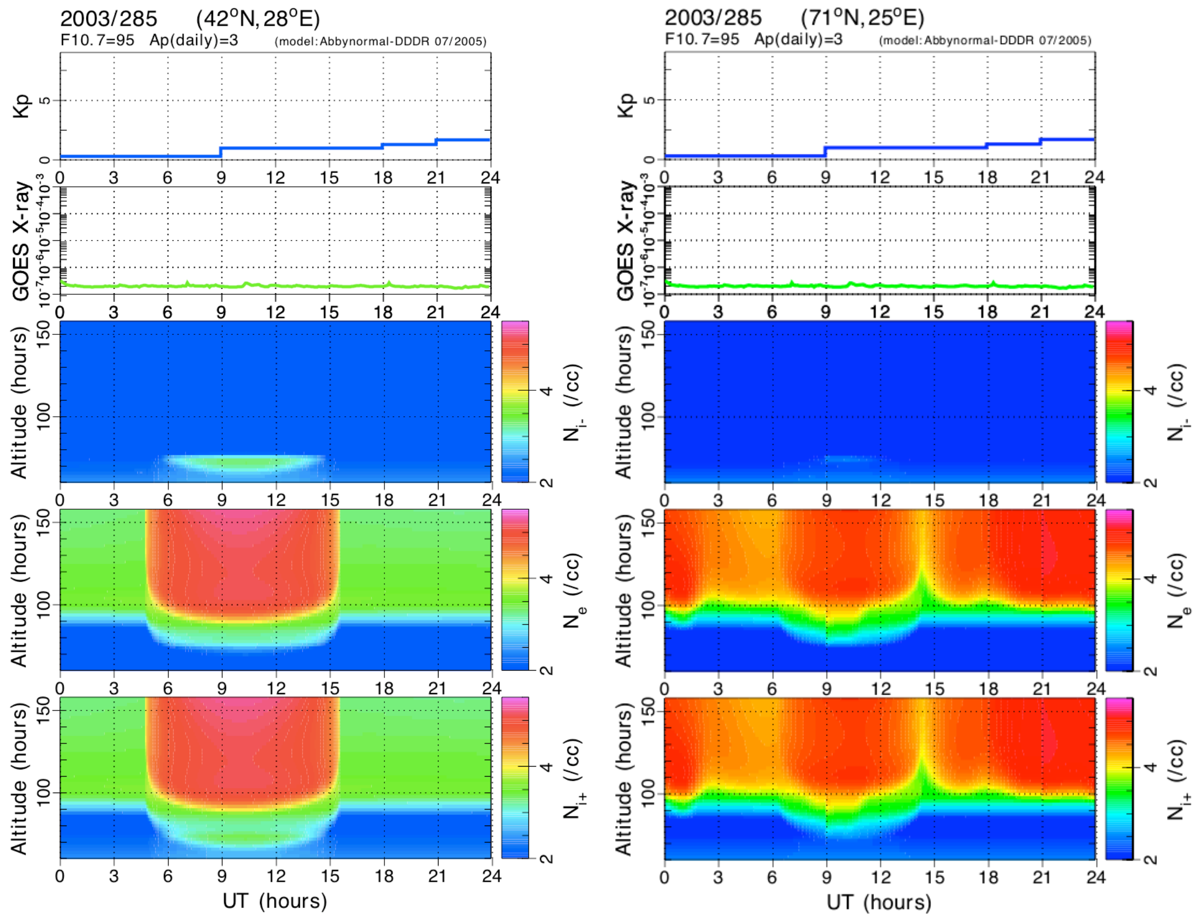
Nordkapphallen, Norway (Lat 71.17, Lon 25.78)

Here is a map of Europe showing the locations of both observatories.



1.3 Structure of the quiet-time ionosphere

To begin with, we want to see how the ionosphere behaves during a quiet period with no solar activity. We will pick a date sufficiently close to the Halloween storms – October 12, 2003. Let us look at some virtual observations that we obtained at the two locations with the ABBYNormal model, below. On the left are results for Silistar, on the right – for Nordkapphallen.



The X-axis shows hours of October 12 in Universal Time (UT). The first panel from the top shows Kp – a planetary index of the geomagnetic activity (http://en.wikipedia.org/wiki/Kp_index). It corresponds to the difference between the largest and smallest value of the geomagnetic field measured every three hours at several ground stations around the world. Usually, active periods with substorms have Kp > 5. We can see that here the index is closer to zero, so the period is quiet.

The second panel shows the intensity of X-ray emission from the Sun incident on Earth, in two wavelengths, measured by a NOAA satellite called GOES (Geostationary Operational Environmental Satellite). We can see that there are no strong X-ray emissions from the Sun on October 12.

The last three panels show color contours of the negative ions, electrons, and positive ions, respectively. The Y-axis represents altitude above the two virtual observatories in kilometers; red and purple colors mean high densities. In this exercise we will focus on the positive ions and electrons only.

Let's think:

- What changes in the densities of ions and electrons above Silistar (left figure) do you notice over the course of the day?
- What is the difference between daytime and nighttime?
- How does the electron density change with altitude?
- Do you see the same diurnal variations over Nordkapphallen (right figure)?

1.4 What creates the ionosphere?

The Sun emits light in all wavelengths. In the ultraviolet range of the spectrum, the photons of light carry enough light to separate electrons from their host atoms in the higher regions of the atmosphere during the day – this we call ionizing radiation. Thus during the day the densities of ions and electrons and the volume in the atmosphere they occupy increase, mainly because of the ionizing radiation coming from the quiet Sun. At night, ions recombine with electrons, and the ionospheric density decreases.

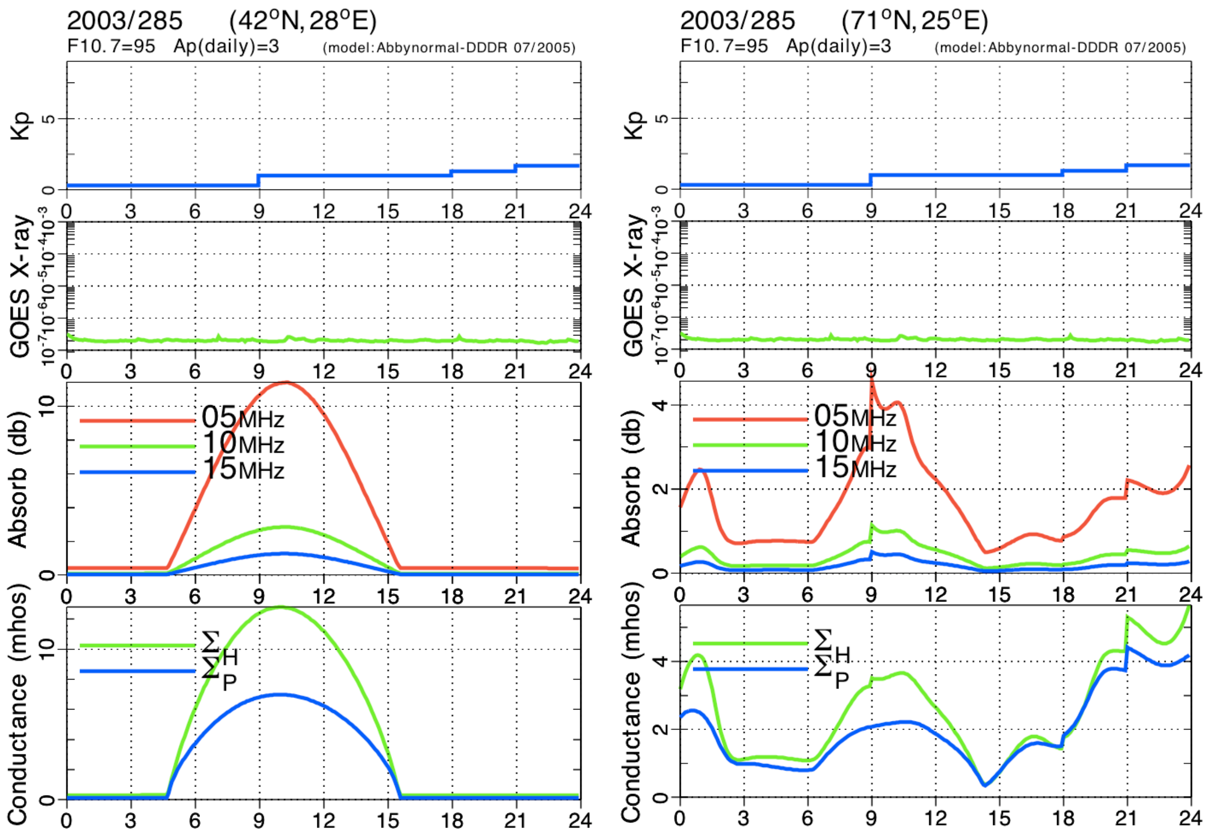
Let's think:

- Looking at the figures above, can you determine the sunrise and sunset times for Silistar and Nordkapphallen on October 12, 2003? Give the approximate times in UT.

1.5 Attenuation of radio signals in the ionosphere

Let us look now at how these changes to the ionosphere modify radio signals. The next two figures are very similar to the first two, but they have two new panels. We will concentrate on the third panel from the top. It shows what fraction of a radio signal that was emitted vertically upward from the two virtual observatories would make it back. This attenuation of the radio signals is measured in decibels. A decibel is a logarithmic unit of relative change – if a radio signal is attenuated 100 times relative to its initial strength, the attenuation equals 10log(100) = 20 dB. In the panel there are color lines showing the attenuation in three radio frequencies – 5, 10, and 15 MHz. As you can see, attenuation depends on the emission frequency.

The last panel from the top shows the electrical conductivity of the atmosphere in the funny unit mho, where mho = 1/ohm measures the inverse of resistivity. The bigger the concentration of charged particles in the atmosphere, the larger the conductivity.

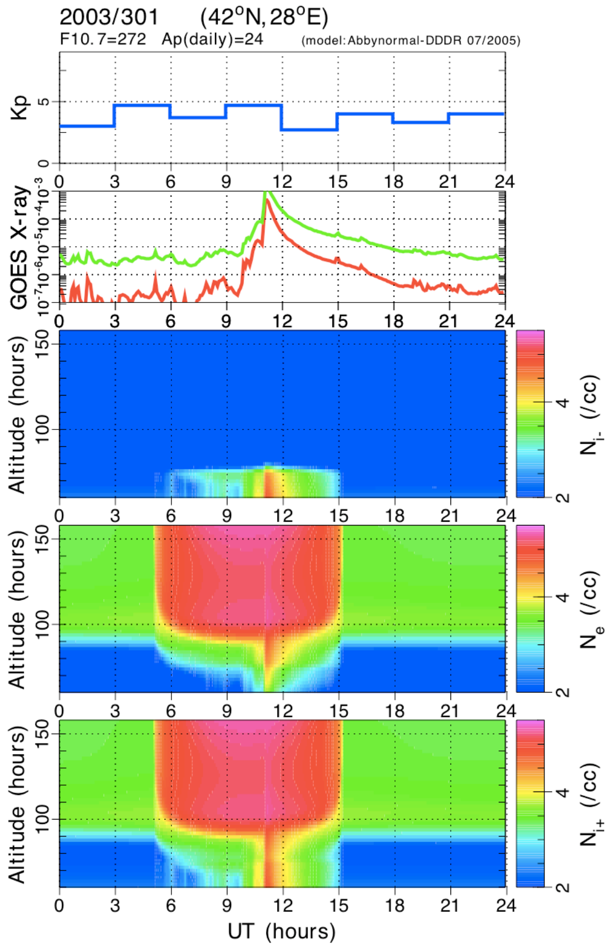


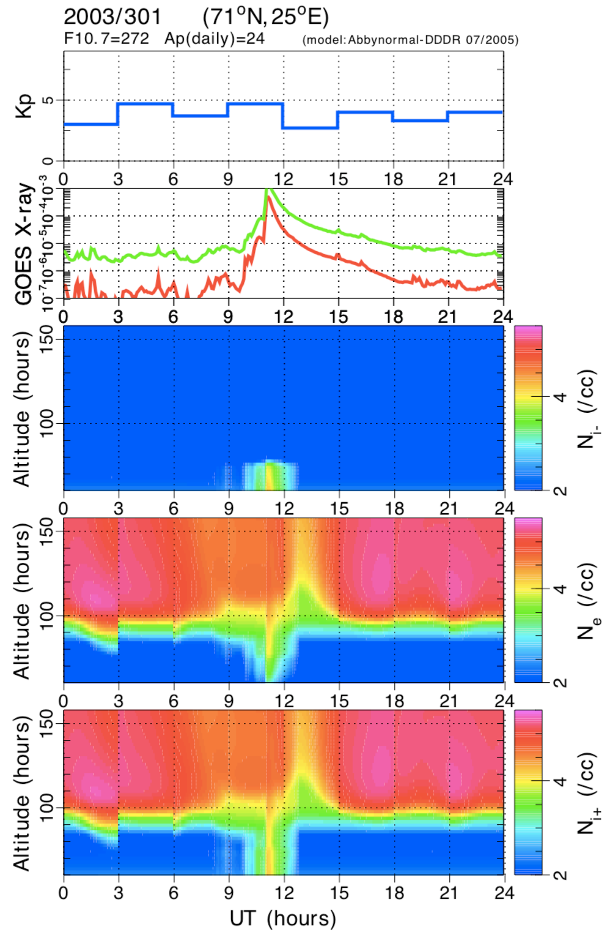
Let's think:

- Describe what connection you find between the diurnal changes in the attenuation of radio signals and ionospheric density, over Silistar and Nordkapphallen.

1.6. The ionosphere during periods of solar activity

Let us see how the ionosphere changed on October 28, 2003 – a day with strong solar activity – above our two virtual observatories. Again, Silistar (Bulgaria) is on the left, Nordkapphallen (Norway) is on the right.



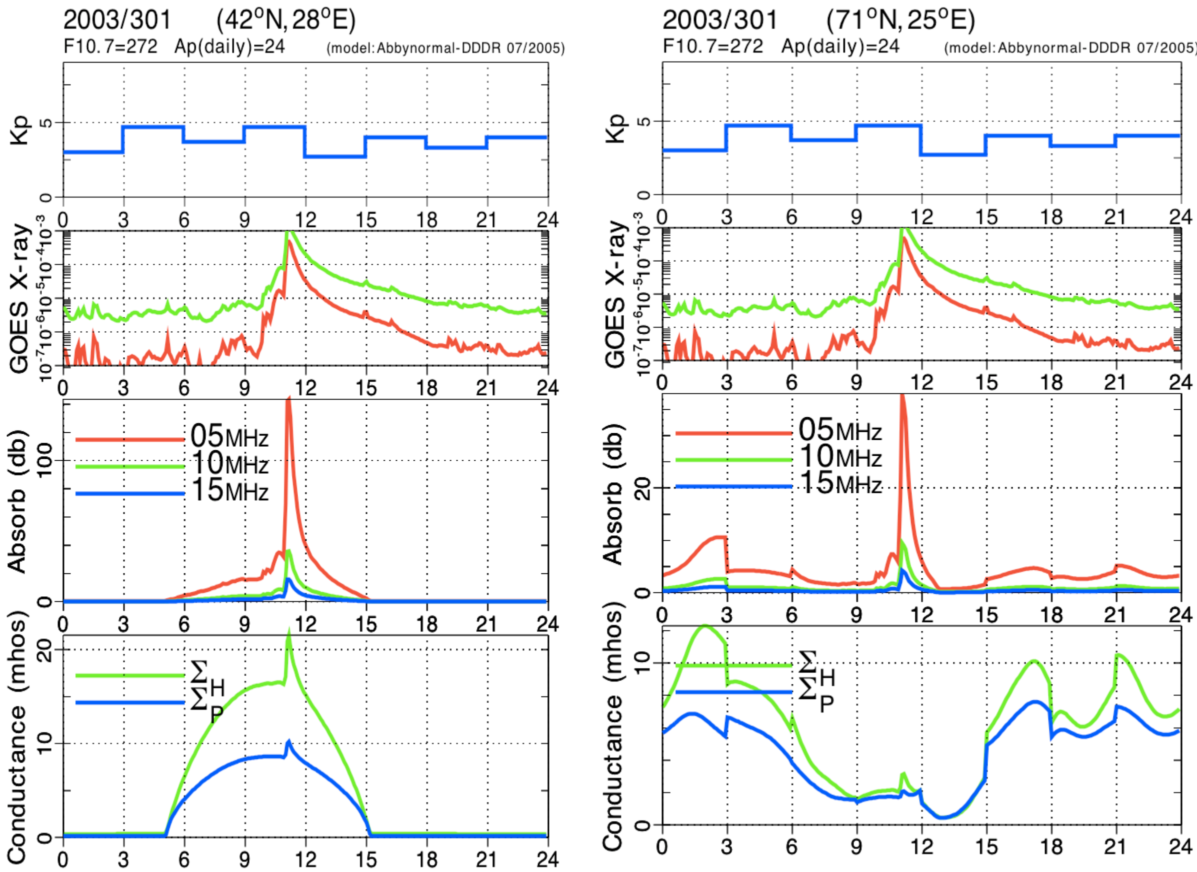


Shortly after 09:00 UT on October 28, a strong solar flare begins on the Sun. It can be seen on the panels showing X-ray emission.

Let's think:

- How does solar activity change the vertical structure of the ion and electron density above Silistar?
- How do the ion and electron densities change above Nordkapphallen?

Now let us explore the attenuation of radio signals above the two observatories:

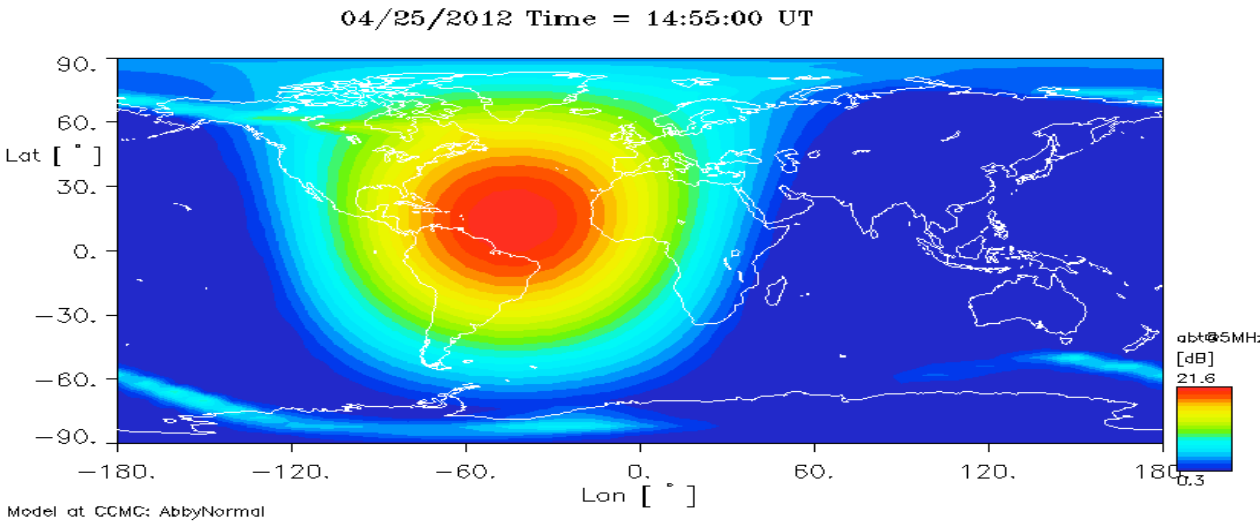


Let's think:

- How does the radio attenuation change above Silistar and Nordkapphallen during this solar flare?
- How does the change correlate with the X-ray emission from the solar flare?

1.7 A global map of radio attenuation in the ionosphere

Finally, let us see what the global effect of solar light on radio signal attenuation is in the Earth's ionosphere.



This map shows the radio attenuation at 5 MHz on a day in 2012.

Let's think:

- What is the main region of strong attenuation over the globe?
- What is the source of the attenuation there?
- Are there other regions of strong attenuation? Where are they?
- Can you make a connection between this map and the virtual observations from Silistar and Nordkapphallen?